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(54) **DIAPHRAGM PUMP**

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F04B 19/00 (2006.01)
F04B 43/04 (2006.01)

(52) **U.S. Cl.**

CPC ***F04D 33/00*** (2013.01); ***F04B 19/006*** (2013.01); ***F04B 43/043*** (2013.01)

(58) **Field of Classification Search**

CPC F04B 43/0045; F04B 43/0054; F04B 43/023; F04B 43/043; F04B 43/14; F04B 45/045; F04B 45/047

USPC .... 417/50, 478, 413.1; 92/103 R

See application file for complete search history.

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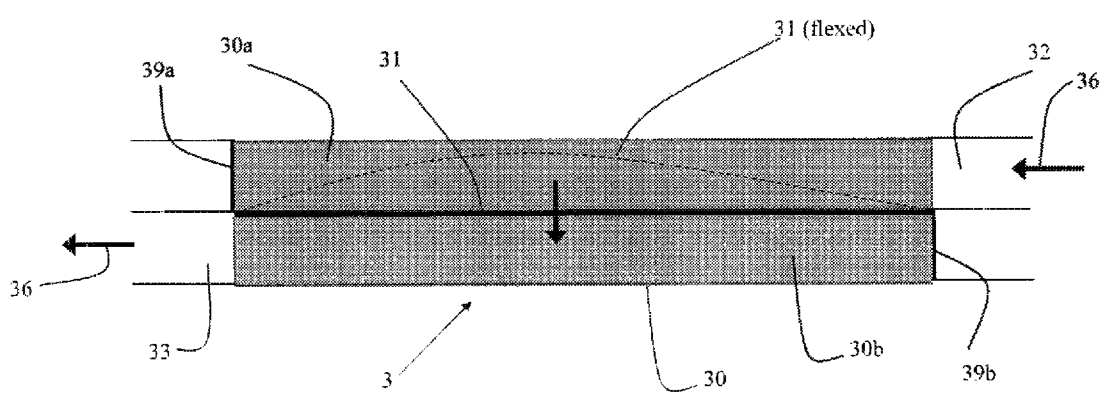
(57) **ABSTRACT**

An apparatus that includes a chamber. The chamber includes an inlet via which process fluid enters the chamber and an outlet via which the process fluid exits the chamber. A diaphragm is fixed in position in the chamber at a periphery of the diaphragm. The diaphragm includes a magnetic fluid therein.

19 Claims, 6 Drawing Sheets



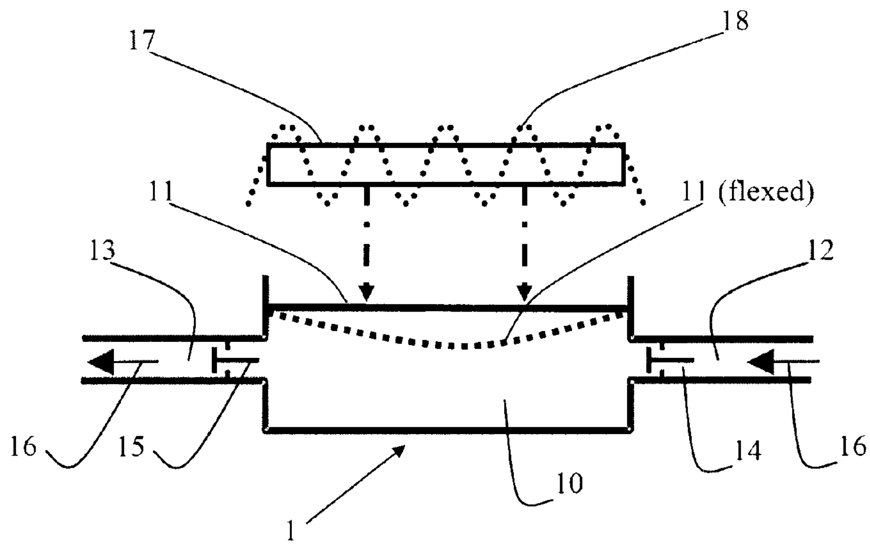


Fig. 1

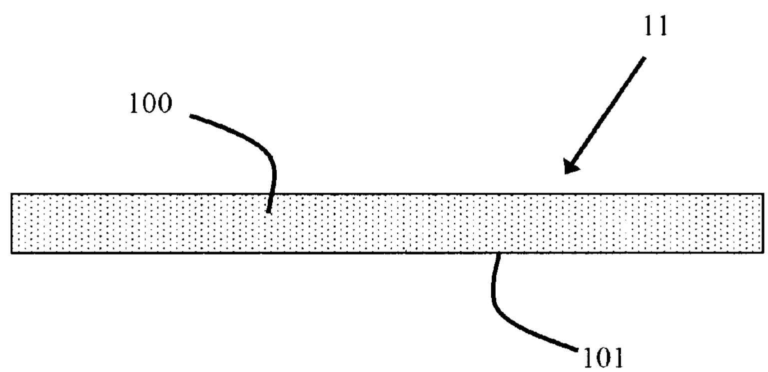


Fig. 2

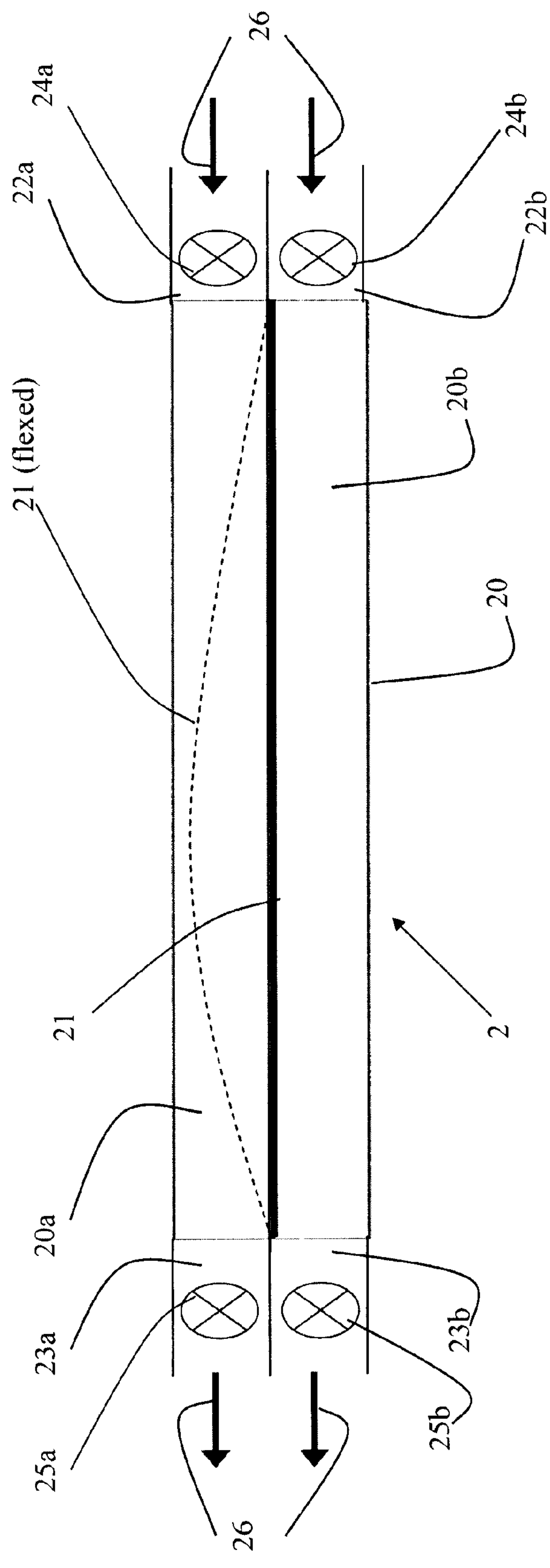


Fig. 3

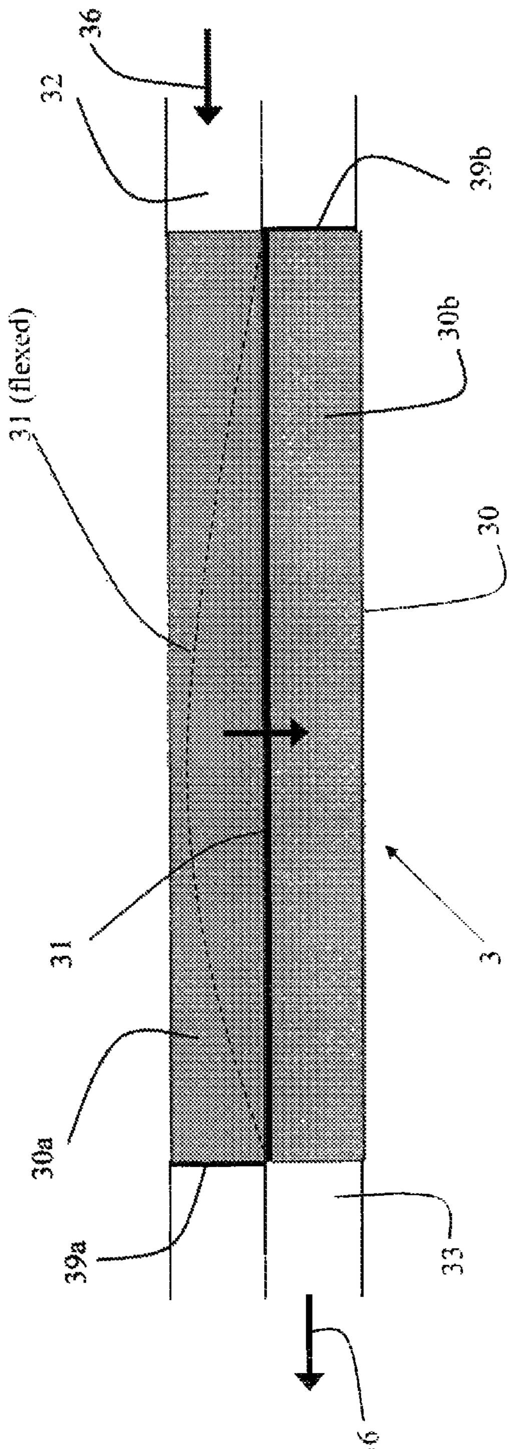


Fig. 4

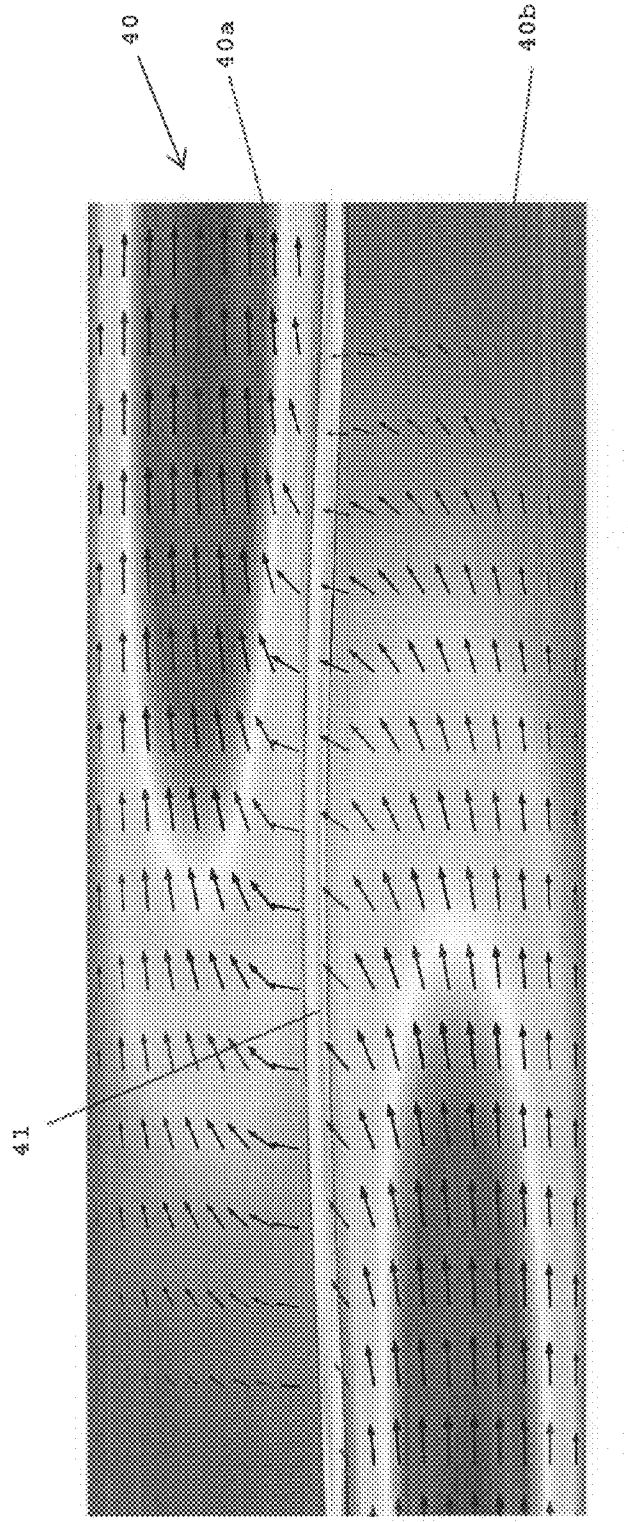


Fig.5

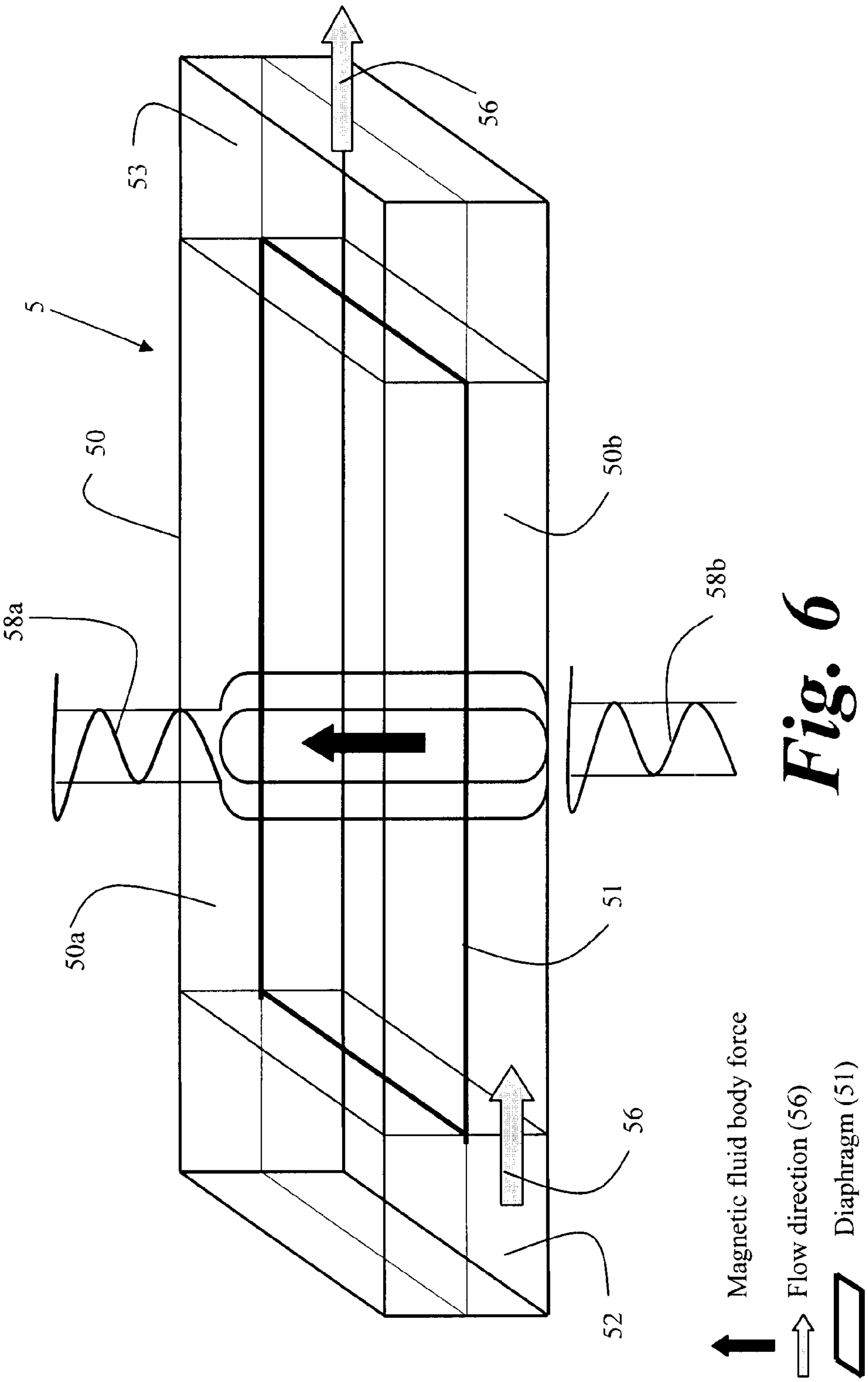

5
50
50a
50b
51
52
53
56
56
58a
58b
Magnetic fluid body force
Flow direction (56)
Diaphragm (51)

Fig. 6

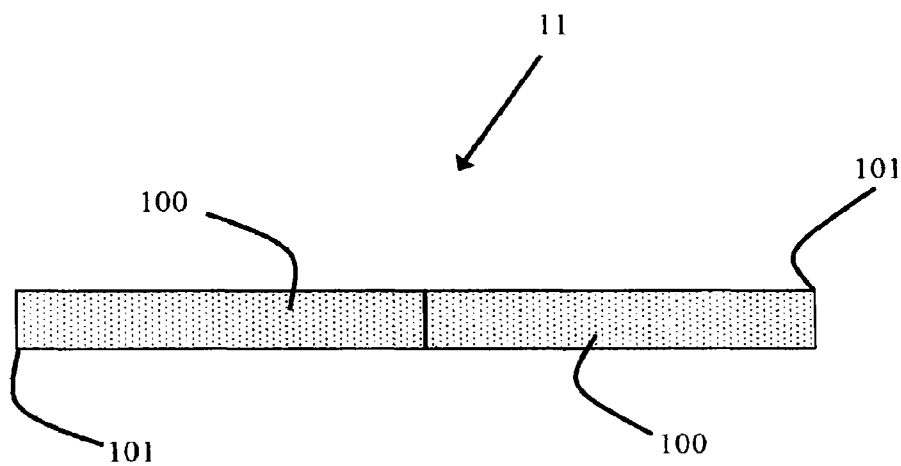


Fig. 7

DIAPHRAGM PUMP

BACKGROUND

1. Field

The embodiments discussed herein relate to a pump that includes a chamber having an inlet and outlet that open and close to allow a non-magnetic process fluid to enter and exit. More specifically, the apparatus described herein relates to a pump that is actuated by a magnetic field. The pump may be a micro-pump.

2. Description of the Related Art

Pumps that use a diaphragm or membrane may be used as positive displacement pumps. Generally, in a positive displacement pump, the diaphragm is sealed with one side facing the fluid to be pumped, and the other side of the diaphragm facing an open environment, such as air. When the diaphragm is flexed, the volume of the pump chamber increases or decreases depending on the direction of the flexure. The flexing of the diaphragm is accomplished via electro-mechanical action.

SUMMARY

According to an embodiment of the present invention, the apparatus includes a chamber through which a process fluid is pumped. The process fluid enters the chamber via an inlet and exits via an outlet. A diaphragm including a magnetic fluid therein is fixed in place in the chamber at an outermost periphery of the diaphragm.

According to another embodiment of the present invention, the apparatus includes a chamber including a plurality of sub-chambers, through which the process fluid is pumped. The apparatus further includes at least one inlet via which process fluid enters one or more of the plurality of the sub-chamber and at least one outlet via which the process fluid exits one or more of the plurality of the sub-chambers. A flexible diaphragm membrane is secured to the chamber between adjacent sub-chambers. The membrane includes an internal closed pocket containing a magnetic fluid therein.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of the invention and many of the attendant advantages thereof will be readily obtained as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings. However, the accompanying drawings and their exemplary depictions do not in any way limit the scope of the inventions embraced by this specification. The scope of the inventions embraced by the specification and drawings are defined by the words of the accompanying claims.

FIG. **1** is a schematic, cross-sectional drawing of the apparatus according to an exemplary embodiment of the present disclosure;

FIG. **2** is a schematic, cross-sectional drawing of the diaphragm including a magnetic fluid according to an exemplary embodiment of the present disclosure;

FIG. **3** is a schematic, cross-sectional view drawing of a dual-chamber apparatus according to an exemplary embodiment of the present disclosure;

FIG. **4** is a schematic, cross-sectional view drawing of the apparatus having a plurality of sub-chambers according to an exemplary embodiment of the present disclosure;

FIG. **5** is a schematic, cross-sectional side view of pressure simulation in a dual-chamber pump according to an exemplary embodiment of the present disclosure;

FIG. **6** is a schematic perspective view drawing of another dual chamber apparatus according to an exemplary embodiment of the present disclosure;

FIG. **7** is a schematic, cross-sectional drawing of the diaphragm including a magnetic fluid according to an exemplary embodiment of the present disclosure.

DETAILED DESCRIPTION

In the following, the present advancement will be discussed by describing a preferred embodiment with reference to the accompanying drawings. However, those skilled in the art will realize other applications and modifications within the scope of the disclosure as defined in the enclosed claims.

FIG. **1** is a schematic, cross-sectional drawing of a single-chamber magnetic fluid pump **1**. The pump **1** includes a chamber **10** formed of side and bottom walls enclosed by a diaphragm **11** (also known as a membrane) fixed in place in the chamber **10**. The diaphragm **11** may be secured to the chamber **10** by compressing a periphery of the diaphragm **11** between wall portions of the chamber **10**, or by other fastening means that allows the diaphragm **11** to flex with minimal risk of breaking or disconnecting from the chamber **10**. For example, the diaphragm **11** may be adhered to the chamber **10** with a suitable adhesive or by a mechanical fastener. It is important that whichever means of fastening is used creates a seal between the diaphragm **11** and the chamber so that the pressure inside the chamber **10** can be manipulated effectively to pump the process fluid. Note that the solid line of the diaphragm **11** in FIG. **1** (and similarly in FIGS. **3** and **4**) is indicative of the diaphragm **11** at rest, and the dotted-line of the diaphragm **11** is indicative of the diaphragm **11** when flexed. In FIG. **1**, the outermost periphery of the diaphragm **11** is fixed in place in the chamber **10**, however, it is understood that an inner portion of the diaphragm **11** could be fixed to the chamber **10** instead, so long as a sealed space is created between the fixed portion of the diaphragm **11** and the inside of the chamber **10**.

The process fluid enters and exits the chamber **10** via a process fluid inlet **12** and a process fluid outlet **13**, respectively. The inlet **12** and the outlet **13** adjoin a wall of the chamber. While FIG. **1** depicts the inlet **12** and the outlet **13** on opposing positions of the side wall/s in the chamber **10**, this is only for the sake of convenience in order to clearly depict the inlet **12** and outlet **13** as distinct. In fact, inlet **12** and outlet **13** may be located proximate to or distant from each other, and may be disposed on any wall surface at any height on the wall surface. For example, it may be advantageous to position at least outlet **13** at or near the bottom of the chamber **10** to reduce any undesired fluid buildup in the bottom and to ensure adequate circulation of the process fluid.

The flow direction **16** of the process fluid through the chamber **10** is shown as arrows in inlet **12** and outlet **13**, respectively. The process fluid moves through the chamber **10** due to flexure of the diaphragm **11**, which contains a magnetic fluid **100** therein, as shown in FIG. **2**. A magnetic field source **17** creates a magnetic field **18**, which can be varied, and which induces the diaphragm **11** to flex due to the magnetic pull or push on the magnetic fluid **100** in the diaphragm **11**. The magnetic field source **17** may be a permanent magnet or an electromagnet, for example.

Furthermore, in the embodiment shown in FIG. **1**, process fluid flow is regulated through the inlet **12** via a unidirectional inlet valve **14**, and through the outlet **13** via a unidirectional outlet valve **15**. The inlet valve **14** allows process fluid to flow in one direction. Specifically, process fluid is allowed to enter the chamber **10** via inlet **12** and inlet valve **14** when the diaphragm **11** flexes in a manner to increase the volume of the chamber **10** (in the case of FIG. **1**, the diaphragm flexes upward to increase the volume of the chamber **10**), and the inlet valve **14** prevents process fluid from exiting via inlet **12** when the diaphragm **11** flexes in a manner to decrease the volume of the chamber **10** (in the case of FIG. **1**, the diaphragm flexes downward to decrease the volume of the chamber **10**). Similarly, the outlet valve **15** only allows flow in one direction. Outlet valve **18**, however, allows process fluid to exit the chamber **10** via outlet **13** when the diaphragm **11** flexes so as to decrease the volume of the chamber **10** and prevents process fluid from entering via outlet **13** when the diaphragm **11** flexes so as to increase the volume of the chamber **10**.

The magnetic fluid **100** in the diaphragm **11** may be a magnetic ferro-fluid, or any other fluid having magnetic properties which can be manipulated by the magnetic field **18**. In contrast, it is noted that the process fluid should not have magnetic properties that would cause the process fluid to interact with the magnetic field **18**.

The diaphragm **11** may be made of a flexible polymer material, or any other durable material that can endure repeated flexure while maintaining the integrity of the diaphragm **11**. The material of the diaphragm **11** must also be compatible with both the process fluid passing through the chamber **10** and the magnetic fluid **100**. That is, the quality and effectiveness of the material of the diaphragm **11** should not easily deteriorate or be weakened due to contact with either or both of the process fluid and the magnetic fluid **100**.

Additionally, the diaphragm **11** may have a single enclosed pocket **101** in which the magnetic fluid **100** is disposed. It is also contemplated that that the diaphragm **11** may have a plurality of smaller pockets therein, as shown for example in FIG. **7**. The pocket **101** (or pockets) may be filled completely with the magnetic fluid **100**, or only partially filled. The amount of magnetic fluid **100** in the pocket **101** may depend on various factors such as flexibility, component material type, strength, and responsiveness to the applied magnetic field **18**, for example.

It is contemplated that the side and bottom walls of the chamber **10** may be made of a non-magnetic material. For example, a non-magnetic stainless steel may be used to form the side and bottom walls of the chamber **10**. Alternatively, the chamber **10** may be made of a polymeric material that is more rigid than the material of the diaphragm **11**.

The magnetic fluid pump **2** shown in FIG. **3** includes some features similar to those found in the embodiment shown in FIG. **1**, however, the pump **2** is a dual-chamber pump. Specifically, pump **2** includes a chamber **20**, which is divided into a first sub-chamber **20***a* and a second sub-chamber **20***b*. The diaphragm **21** is disposed between the first and second sub-chambers **20***a* and **20***b*. Furthermore, each of the first and second sub-chambers **20***a* and **20***b* includes a distinct process fluid inlet **22***a* and **22***b*, respectively, and a distinct process fluid outlet **23***a* and **23***b*, respectively. Similarly, each of the first and second sub-chambers **20***a* and **20***b* also includes distinct unidirectional inlet valves **24***a* and **24***b*, respectively, and distinct unidirectional outlet valves **25***a* and **25***b*, respectively, via which the process fluid flows through each sub-chamber. The fluid flow direction **26** is indicated by the arrows in the respective inlets **22***a* and **22***b* and outlets **23***a* and **23***b*.

As with the movement of the process fluid in pump **1** of FIG. **1**, process fluid flows through pump **2** by means of inducing diaphragm **21** to flex via a magnetic field source (not shown in FIG. **3**) that manipulates the magnetic fluid (not shown in FIG. **3**) in diaphragm **21**.

Although the chamber **20** has a fixed volume overall, the volume of first and second sub-chambers **20***a* and **20***b* varies depending on the direction in which diaphragm **21** is flexing. That is, when diaphragm **21** flexes upward into first sub-chamber **20***a* (as depicted in FIG. **3**), the volume of first sub-chamber **20***a* decreases, thereby increasing the internal pressure and forcing process fluid to exit first sub-chamber **20***a* via the outlet valve **25***a*. Simultaneously, the upward flexure of diaphragm **21** increases the volume of second sub-chamber **20***b*, thereby creating a vacuum and drawing in process fluid via the inlet valve **24***b*. Then, when diaphragm **21** flexes downward into second sub-chamber **20***b*, the volume of second sub-chamber **20***b* decreases, thereby increasing the internal pressure and forcing the process fluid that was just drawn therein to exit second sub-chamber **20***b* via the outlet valve **25***b*. Further, the downward flexure of diaphragm **21** increases the volume of first sub-chamber **20***a*, thereby creating a vacuum and drawing in process fluid via the inlet valve **24***a*. Accordingly, process fluid is cycled into one sub-chamber and out of the adjacent sub-chamber with each flex of diaphragm **21**.

In another embodiment show in FIG. **4**, a magnetic fluid pump **3** includes a chamber **30** divided into a first sub-chamber **30**a and a second sub-chamber **30***b* by diaphragm **31**. Process fluid enters first sub-chamber **30***a* via process fluid inlet **32** and exits second sub-chamber **30***b* via process fluid outlet **33**. The fluid flow direction **36** is indicated by the arrows in inlet **32** and outlet **33** and through the diaphragm **31**. Although F*ig*. **4** does not depict unidirectional valves in pump **3** like those in pumps **1** and **2**, it is understood that valves may be incorporated therein to assist in the process fluid flow.

Unlike the distinct first and second sub-chambers **20***a* and **20***b* of the chamber **20** in pump **2**, process fluid is able to pass between first and second sub-chambers **30***a* and **30***b* of the chamber **30** in pump **3**. Process fluid is allowed to pass through diaphragm **31** because, in addition to including a magnetic fluid in diaphragm **31**, diaphragm **31** includes at least a portion thereof that is permeable in only one direction, for example, downward or in the direction of gravity as shown in FIG. **4**. Thus, as depicted in F*ig*. **4**, the first sub-chamber **30***a* does not include a distinct outlet and the second sub-chamber **30***b* does not include a distinct inlet. Instead, first sub-chamber **30***a* includes the inlet **32** and the rest of the walls in the first sub-chamber **30***a* are fixed (shown as fixed wall **39***a*). Similarly, second sub-chamber **30***b* includes the outlet **33** and the rest of the walls in the second sub-chamber **30***b* are fixed (shown as fixed wall **39***b*). It is contemplated, however, that each of the first and second sub-chambers **30***a* and **30***b* may have an access aperture (not shown) through the fixed walls **39***a* and **39***b*, respectively, which may be used as an outlet for cleaning, repair, or other purposes.

In the embodiment of pump **3** shown in FIG. **4**, the process fluid flowing into the first sub-chamber **30***a* may be gravity fed with static pressure. Thus, in combination with the magnetic fluid in diaphragm **31**, upon causing the diaphragm **31** to flex by way of a magnetic field source (not shown in F*ig*. **4**, see FIG. **1**), process fluid is drawn into the first sub-chamber **30***a* via the inlet **32**, passes through the permeable portion of diaphragm **31**, and exits the second sub-chamber **30***b* via the outlet **33**. Therefore, the fluid flow path begins in the first sub-chamber **30***a* and ends by exiting the second sub-chamber **30***b*.

FIG. **5** depicts a cross-sectional view of a simulation of a pressure gradient in a pump chamber **40**. The chamber **40** is divided into a distinct first sub-chamber **40**_a_ and a distinct second sub-chamber **40**_b_ by a diaphragm **41**. The diaphragm **41** is like the diaphragms **11** and **21** of the embodiments shown in FIGS. **1** and **3**, respectively, in that diaphragm **41** contains magnetic fluid therein and is not permeable. The direction of the fluid velocity vectors with pressure contours, during flexure of the diaphragm **41**, is also shown as arrows in the first and second sub-chambers **40**_a_ and **40**_b_. The change in pressure from the second sub-chamber **40**_b_ to the first sub-chamber **40**_a_ drives the flow of fluid from one sub-chamber into the other.

FIG. **6** depicts a schematic perspective view of a dual-chamber pump **5** like the pump **2** in FIG. **3**. Pump **5** includes a chamber **50** divided by diaphragm **51** into a first sub-chamber **50**_a_ and a second sub-chamber **50**_b_. Magnetic flux lines are shown such that flux line **58**_a_ indicates that the magnetic field source (not shown) is on and flux line **58**_b_ indicates that the magnetic field source is off As such, the diaphragm **51** is manipulated upward so that process fluid enters second sub-chamber **50**_b_ via inlet **52**, and the process fluid previously drawn into the first sub-chamber **50**_a_ is expelled from the first sub-chamber **50**_a_ via the outlet **53**. Accordingly, the process fluid flow direction **56** is shown by the arrows in inlet **52** and outlet **53**. It is noted that the distinct inlet of the first sub-chamber **50**_a_ and the distinct outlet of the second sub-chamber **50**_b_ are not labeled in FIG. **6**.

Obviously, numerous modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described herein.

The invention claimed is:

1. An apparatus, comprising:

a chamber;

an inlet via which process fluid enters the chamber;

an outlet via which the process fluid exits the chamber; and

a diaphragm including one or more closed pockets, each pocket having a magnetic fluid therein, a periphery of the diaphragm being fixed in position in the chamber, and the diaphragm includes a permeable section that is permeable to the process fluid in only a single direction.

2. The apparatus according to claim **1**, further comprising a magnetic field source that creates a magnetic field, in response to which the diaphragm flexes to pump the process fluid through the chamber.

3. The apparatus according to claim **1**, wherein the diaphragm flexes in response to a magnetic field, and

wherein an intensity of the magnetic field determines a magnitude of flexure of the diaphragm.

4. The apparatus according to claim **1**, wherein the diaphragm encloses a portion of the chamber and flexes in opposite directions, depending on a magnetic field created near the diaphragm, so as to increase or decrease a volume of the portion of the chamber, thereby pumping the process fluid through the portion of the chamber, and

wherein when the volume of the portion of the chamber increases, the process fluid is drawn into the chamber, and when the volume of the portion of the chamber decreases, the process fluid is expelled from the chamber.

5. The apparatus according to claim **1**, wherein the inlet includes a unidirectional valve.

6. The apparatus according to claim **1**, wherein the outlet includes a unidirectional valve.

7. The apparatus according to claim **1**, wherein the inlet and the outlet are disposed on one or more wall portions of the chamber, the one or more wall portions being enclosed by the diaphragm such that the inlet and the outlet are on a same side of the diaphragm.

8. An apparatus, comprising:

a chamber divided into first and second sub-chambers;

an inlet via which process fluid enters the chamber;

an outlet via which the process fluid exits the chamber; and

a diaphragm including one or more closed pockets, each pockets having a magnetic fluid therein, a periphery of the diaphragm being fixed in position to interior walls of the chamber at a perimeter of the diaphragm between the first and second sub-chambers, and the diaphragm includes a permeable section that is permeable to the process fluid in only a single direction,

wherein, the first sub-chamber is disposed on a first side of the diaphragm and the second sub-chamber is disposed on a second side of the diaphragm opposing the first side.

9. The apparatus according to claim **8**, wherein the inlet is a first inlet and the process fluid enters the first sub-chamber via the first inlet,

wherein the outlet is a first outlet and the process fluid exits the first sub-chamber via the first outlet,

wherein the apparatus further comprises:

a second inlet via which the process fluid enters the second sub-chamber; and

a second outlet via which the process fluid exits the second sub-chamber; and

wherein the first inlet and the first outlet accommodate pumping the process fluid through the first sub-chamber, and the second inlet and the second outlet accommodate pumping the process fluid through the second sub-chamber.

10. The apparatus according to claim **9**, wherein the diaphragm flexes according to a magnetic field created near the diaphragm thereby affecting a volume capacity of the first and second sub-chambers simultaneously,

wherein when the magnetic field is such that the diaphragm flexes away from the first sub-chamber and into the second sub-chamber, the process fluid is drawn into the first sub-chamber via the first inlet due to an increase in the volume capacity of the first sub-chamber and the process fluid is expelled from the second sub-chamber via the second outlet due to a decrease in the volume capacity of the second sub-chamber, and

wherein when the magnetic field is such that the diaphragm flexes into the first sub-chamber and away from the second sub-chamber, the process fluid is drawn into the second sub-chamber via the second inlet due to an increase in the volume capacity of the second sub-chamber and the process fluid is expelled from the first sub-chamber via the first outlet due to a decrease in the volume capacity of the first sub-chamber.

11. The apparatus according to claim **8**, wherein the inlet accommodates pumping the process fluid into the first sub-chamber, and

wherein the outlet accommodates pumping the process fluid out of the second sub-chamber.

12. The apparatus according to claim **11**, wherein when the process fluid is pumped, the process fluid passes from the first sub-chamber into the second sub-chamber via the permeable section of the diaphragm.

13. An apparatus, comprising:

a chamber including a plurality of sub-chambers;

at least one inlet via which process fluid enters one or more of the plurality of the sub-chambers;

at least one outlet via which the process fluid exits one or more of the plurality of the sub-chambers; and a flexible diaphragm secured to interior walls of the chamber at a perimeter of the diaphragm between adjacent sub-chambers, the diaphragm including one or more internal closed pockets, each pocket containing a magnetic fluid therein, and the diaphragm includes a permeable section that is permeable to the process fluid in only a single direction.

14. The apparatus according to claim **13**, wherein the diaphragm flexes in response to a magnetic field thereby pumping the process fluid through the plurality of sub-chambers.

15. The apparatus according to claim **13**, further comprising a magnetic field source that creates a magnetic field, in response to which the diaphragm flexes to pump the process fluid through the chamber.

16. The apparatus according to claim **13**, wherein when the process fluid is pumped, the process fluid passes from a first sub-chamber of the plurality of sub-chambers into a second sub-chamber of the plurality of sub-chambers via the permeable section of the diaphragm.

17. The apparatus according to claim **14**, wherein the plurality of sub-chambers includes a first sub-chamber and a second sub-chamber, and

wherein the diaphragm flexes according to a magnetic field created near the diaphragm thereby affecting a volume capacity of the first and second sub-chambers simultaneously.

18. The apparatus according to claim **17**, wherein the first sub-chamber includes the at least one inlet having a valve disposed at a wall portion of the first sub-chamber, and

wherein the second sub-chamber includes the at least one outlet having a valve disposed at a wall portion of the second sub-chamber.

19. The apparatus according to claim **17**, further comprising a magnetic field source that creates the magnetic field, so as to pump the process fluid into the first sub-chamber via the at least one inlet and out of the second sub-chamber via the at least one outlet.

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